

# $J/\psi$ Pair Production at the Tevatron with $\sqrt{s} = 1.96$ TeV

Cong-Feng Qiao<sup>1,2</sup> and Li-Ping Sun<sup>1</sup>

<sup>1</sup>*College of Physical Sciences, Graduate University of Chinese Academy of Sciences*

*YuQuan Road 19A, Beijing 100049, China and*

<sup>2</sup>*Theoretical Physics Center for Science Facilities (TPCSF), CAS*

*YuQuan Road 19B, Beijing 100049, China*

## Abstract

We study the  $J/\psi$  pair production issue at the Fermilab Tevatron Run II with the center-of-mass energy  $\sqrt{s} = 1.96$  TeV. Both the color-singlet and -octet production mechanisms are considered. Our result shows that the transverse momentum( $p_T$ ) scaling behaviors of double  $J/\psi$  differential cross sections in color-singlet and -octet deviate distinctively from each other while  $p_T$  is larger than 8 GeV, and with the luminosity of  $5\text{fb}^{-1}$  the  $J/\psi$  pair events from color-singlet scheme are substantially measurable in Tevatron experiments, even with certain lower transverse momentum cut. Hence the Tevatron is still possibly a platform to check the heavy quarkonium production mechanism.

**PACS numbers:** 12.38.Bx, 13.85.Fb, 14.40.Lb.

The Tevatron [1, 2] Run II with the center-of-mass energy  $\sqrt{s} = 1.96$  TeV is a good platform for the study of the heavy quark mesons. In this brief report, we reevaluate the  $J/\psi$  pair production rate at the Tevatron in the framework of non-relativistic chromodynamics (NRQCD) [3]. In the color-singlet model, the partonic subprocesses start at order  $\alpha_s^4$ , which include  $g + g \rightarrow J/\psi + J/\psi$  and  $q + \bar{q} \rightarrow J/\psi + J/\psi$ . Intuitively, the latter, the quark-antiquark annihilation process, contributes less than the former at the Tevatron, hence in the following analysis we mainly focus on the gluon-gluon process as shown in Figure 1.

The differential cross section for  $J/\psi$  pair hadroproduction reads

$$\frac{d\sigma}{dp_T}(pp \rightarrow 2J/\psi + X) = \sum_{a,b} \int dy_1 dy_2 f_{a/p}(x_a) f_{b/p}(x_b) 2p_T x_a x_b \frac{d\hat{\sigma}}{dt}(a + b \rightarrow 2J/\psi), \quad (1)$$

where  $f_{a/p}$  and  $f_{b/p}$  denote the parton densities in proton or antiproton;  $y_1, y_2$  are the rapidity of the two produced  $J/\psi$ s. The partonic scattering process, the gluon-gluon to polarized and unpolarized  $J/\psi$  pair differential cross section  $\frac{d\hat{\sigma}}{dt}$ , can be calculated in the standard method, which had been performed before in Refs.[4, 5], and we confirm the analytic result.

In NRQCD, the color-octet scheme is guaranteed [6]. For the  $J/\psi$  pair production process, the typical Feynman diagrams are shown in Figure 1. Part of it, the lower two ones in CO mechanism, the fragmentation processes, in the figure was evaluated in Ref.[7]. In this work, we consider not only the  $J/\psi$  pair in configuration of  $|\bar{c}\bar{c}[^3S_1^{(8)}]gg\rangle|c c[^3S_1^{(8)}]gg\rangle$ , but also in configuration of  $|\bar{c}\bar{c}[^3S_1]\rangle|c c[^3S_1^{(8)}]gg\rangle$ , though the latter contributes less in the end.

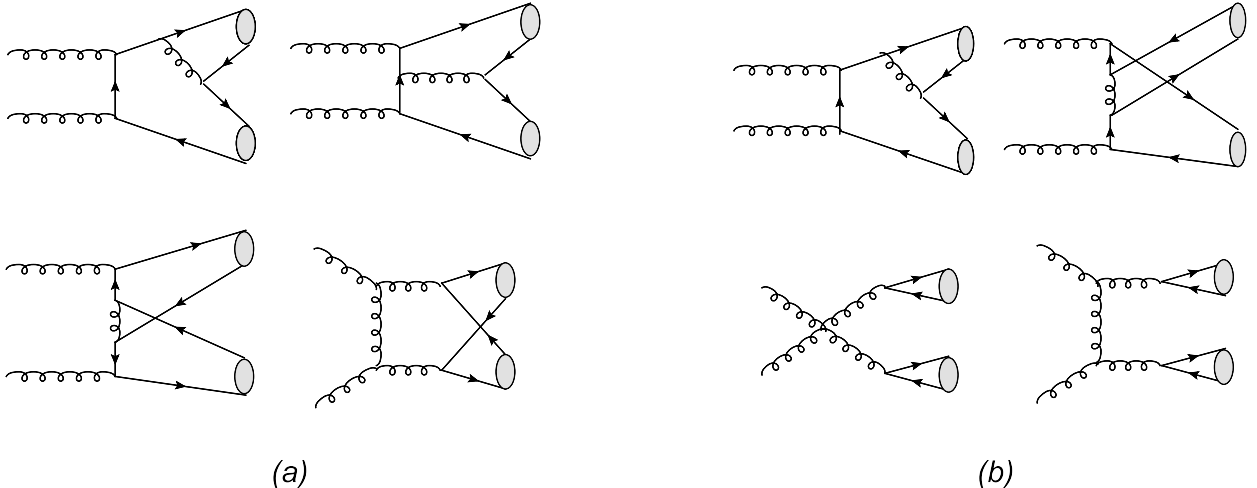


FIG. 1: The typical Feynman diagrams of  $J/\psi$  pair production at leading order. Figure (a) belongs to the CS scheme, while Figure (b) is the CO case .

TABLE I: The integrated cross sections of  $J/\psi$  pair production under various low transverse momentum cuts. Here,  $\perp\perp$  represents the situation in which both  $J/\psi$ s are transversely polarized,  $\parallel\parallel$  represents that both  $J/\psi$ s are longitudinally polarized,  $\parallel\perp$  represents that one  $J/\psi$  is longitudinally polarized and the other is transversely polarized. The  $tot_{18}$  in the last row represents the double  $J/\psi$  yields from CS + CO production scheme for reference.

	CS Model					CO Model				
$\sigma \setminus p_{Tcut}$	3 GeV	4 GeV	5 GeV	6 GeV	7 GeV	3 GeV	4 GeV	5 GeV	6 GeV	7 GeV
$\perp\perp$	0.520pb	0.145pb	0.044pb	0.015pb	5.408fb	0.047pb	0.033pb	0.021pb	0.014pb	8.869fb
$\parallel\parallel$	0.214pb	0.074pb	0.025pb	8.927fb	3.411fb	0.345fb	0.102fb	0.032fb	0.011fb	0.004fb
$\parallel\perp$	0.547pb	0.131pb	0.032pb	8.424fb	2.466fb	5.303fb	2.640fb	1.289fb	0.636fb	0.323fb
$tot$	1.278pb	0.348pb	0.101pb	0.032pb	0.011pb	0.053pb	0.035pb	0.023pb	0.014pb	9.195fb
$tot_{18}$	—	—	—	—	—	0.040pb	0.011pb	3.384fb	1.107fb	0.400fb

Except for the difference in CO and CS non-perturbative matrix element projections, the perturbative calculations of Feynman diagrams for both CS and CO are similar. In numerical calculation, we enforce the Tevatron experimental condition, the pseudorapidity cut  $|\eta(J/\psi)| < 2.0$ , the central-of-mass energy  $\sqrt{S} = 1.96$  TeV for Tevatron Run II. The input parameters take the values [2]

$$m_c = 1.5 \text{ GeV}, \quad |R(0)|^2 = 0.8 \text{ GeV}^3, \quad \langle \mathcal{O}_8^{J/\psi}(^3S_1) \rangle = 0.012 \text{ GeV}^3. \quad (2)$$

With the above formulas and inputs, one can readily obtain the polarized  $J/\psi$  pair production cross section at the Tevatron. In the numerical calculation, the parton distribution of CTEQ5L [8] is used. The integrated cross section  $\sigma(p p \rightarrow J/\psi J/\psi)$  with various  $p_T$  lower bounds is presented in Table I for the CS and CO production schemes respectively, where the branching fraction of  $B(J/\psi \rightarrow \mu^+ \mu^-) = 0.0597$  is taken into account.

The spectra of double- $J/\psi$  exclusive production as a function of transverse momentum  $p_T$  are illustrated in Figures 2 and 3. Figure 2 shows that at large  $p_T$ , in the CS scheme the contribution from  $\perp\perp$  case dominates the process, while in the CO case, the  $\perp\perp$  dominates the process in all  $p_T$  region. Figure 3 indicates that the conventional CS production scheme dominates over the CO one in relatively low- $p_T$  region, while  $p_T < 8$  GeV.

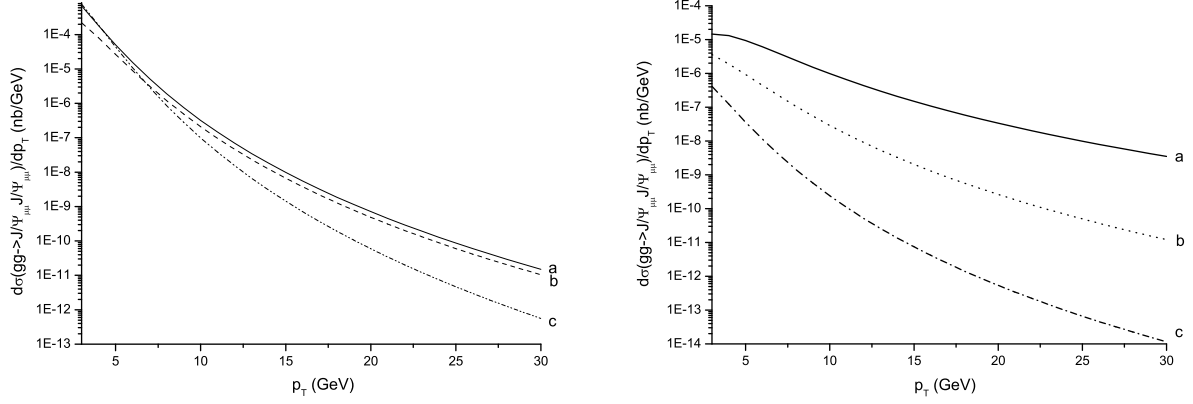


FIG. 2: The differential cross-section of  $J/\psi$  pair production versus  $p_T$  at the Tevatron. The left figure represents the yields from color-singlet, the lines from top to bottom, i.e. a, b and c, denote  $\perp\perp$ ,  $|||$ , and  $||\perp$  cases, respectively. The right figure represents the yields from color-octet, the lines from top to bottom, i.e. a, b and c, denote  $\perp\perp$ ,  $||\perp$ , and  $|||$  cases, respectively.

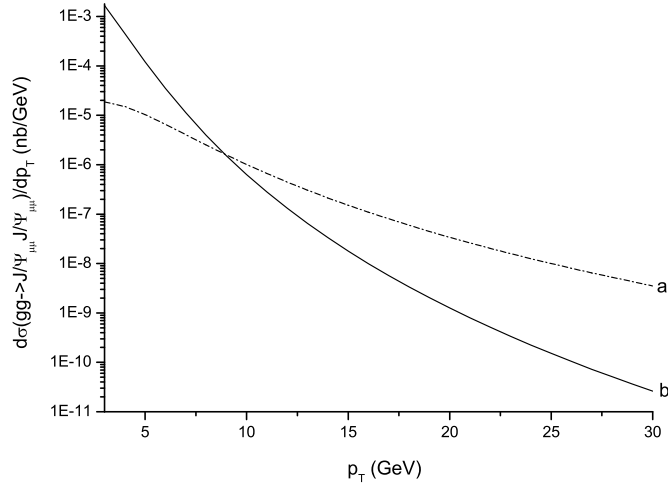


FIG. 3: The differential cross-section of  $J/\psi$  pair production versus  $p_T$  at the Tevatron. Lines a and b, represent the yields from color-octet and color-singlet in unpolarized case, respectively.

In conclusion, we evaluate the  $J/\psi$  pair production at the Fermilab Tevatron Run II energy. With the luminosity of  $\sim 5 \text{ fb}^{-1}$ , we find that there is a large number of  $J/\psi$  pair events produced there. Imposing a low transverse momentum cut of 7 GeV, the observed

data should come only from the CO mechanism, and the detection efficiency be 10% or lower. In all, it is very hopeful to observe the  $J/\psi$  pair production process in the Tevatron II experiments, and even to check the charmonium production mechanism through it.

## Acknowledgments

We would like to thank Dmitry Bandurin of D0 Collaboration for bringing our attention to this issue. This work was supported in part by the National Natural Science Foundation of China(NSFC) under Grant No. 10935012, 10821063 and 11175249.

- 
- [1] E. Braaten, S. Fleming and A.K. Leibovich Phys. Rev. D**63**, 094006(2001).
  - [2] P. Cho and Leibovich, Phy. Rev. D**53**, 150(1996); *ibid*, 6203(1996).
  - [3] G.T. Bodwin, E. Braaten, and G.P. Lepage, Phys. Rev. D**51**, 1125(1995).
  - [4] Cong-Feng Qiao, Phys. Rev. D**66**, 057504(2002).
  - [5] Cong-Feng Qiao, Li-Ping Sun, and Peng Sun, J. Phys. G**37**, 075019(2010).
  - [6] G.T. Bodwin, E. Braaten, and G.P. Lepage, Phys. Rev. D**46**, R3703(1992); E. Braaten and S. Fleming, Phys. Rev. Lett. **74**, 3327(1995).
  - [7] V. Barger, S. Fleming, and R.J.N. Phillips, Phys. Lett. B**371**, 111(1996).
  - [8] CTEQ Collaboration, H.L. Lai *et al.*, Eur. Phys. J. C**12**, 375(2000).